

# LEBICHOT S ET ALL. Grey level intercepts distributions and grain size estimation

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## ABSTRACT:

Image analysis suffers from the obsession of many users to attempt processing images in the same way as the human visual system acts. This is particularly true when considering the determination of an average grain size in materials. Whereas the human eye easily outlines individual grains in an image, it may become a real puzzle for an automatic imaging software to do so. Most of the existing systems try to individualize grains on the basis of their boundaries, which are seldom closed, due for example to incomplete etching, natural reflectance variation, or even bad image acquisition. The intercept method, based on the recognition of transitions along chosen directions, has brought an elegant solution to the problem: it makes possible a robust statistical estimate of the grain population. Results can be displayed in the form of polar plots of intercept length or intercept number distributions. The method is usually applied on binary images obtained from a simple thresholding operation, however recent works have shown the benefits of developing a grey-level intercepts alternative. In this paper, we present the advantages and the characteristics of such a method for the determination of grain size statistics. We propose some improvement to the existing grey-level method and an original approach to present the method's results. Some examples illustrate the whole presentation.

Keywords: chord length, grain size, materials, metallography, texture

## 1 GRAIN SIZE DETERMINATION

Metallographers know since a long time that the grain size distribution affects mechanical properties of materials. As a result, grain size analysis has always been a matter of importance. Most of the time, the estimation of mean size and variance - instead of the whole distribution - are sufficient to suit the characterization need. This is particularly true for homogeneous material structures that tend to generate a normal grain size distribution.

To perform the measurement, metallographers examine polished sections sampled from a specific location under the microscope. Often, a chemical etching is applied to reveal grain boundaries. This brings all the classical problems bounded to sample preparation: a too short etching time leads to insufficient grain revelation whereas an excessive exposure to the etching agent induces intense pitting. Once grain boundaries are revealed, an automatic computation is performed using either individual object analysis (planimetric method) or the binary intercept method. These are the only two accepted procedures to compute grain size distributions in metallic materials following norm ASTM 1382 "G".

The planimetric method is based on area measurements. This requires all boundaries to be perfectly closed so that grains can be detected. The detection can be performed manually or using automatic

image processing methods such as a distance-based watershed (Pirard and Delanaye, 1994) or a grey-level watershed (Beucher and Meyer, 1992). Manual detection is a trivial but tedious operation. On the other hand, the watershed is very sensitive to the quality of the image and is hard to parameterize adequately (choice of markers).

The intercept method is based on counting the number of segments determined within a set of objects cut by a set of parallel scan lines along a series of directions (Russ and Dehoff, 2000; Launeau and Robin, 1996; Underwood, 1970; Saltikov, 1958). The advantage of the method is that it still gives a statistical estimation of the grain size distribution even when individual contours are only partially outlined. This is particularly interesting as it matches the real operation conditions. A prerequisite however, is that the subset of contours revealed by etching is a dense and unbiased sample (e.g. no preferential etching due to crystallographic orientation).

## 2 LIMITATIONS OF THE BINARY INTERCEPT METHOD

The intercept method is a stereological tool defined on binary images. This means that the preliminary image thresholding operation to be performed is totally independent. Hence, the binary intercept method takes advantage of simpler images and simpler algorithms, but this is not without consequences:

- a. The result is not robust with respect to the grey-level threshold. This is particularly true when using absolute thresholding on images affected by reflectance fluctuations due to uneven lighting, bad specimen leveling, incomplete etching, etc. In such cases, some boundaries are not detected whereas many spurious ones do appear;
- b. Intercept measurements can only be performed with high accuracy along the principal directions of the grid. In order to explore anisotropy it is mandatory to define a line representation for each orientation (Bresenham lines, Soille 1999). Alternatively, image rotation has to be performed using an adequate interpolation algorithm (e.g. nearest neighbor re-sampling). It can be shown that rotations applied to binary images lead to artificial intercept counts. Those spurious intercepts have to be filtered out by applying additional processing such as the *linear filter* suggested by Launeau (1990).

## 3 THE GREY-LEVEL INTERCEPT METHOD

By definition, the grey-level intercept method deals directly with the original grey-level image. Similarly to the binary intercept method, the approach is to detect transitions along scan lines drawn along several directions.

The major interests of a grey-level intercept method are the following:

- a. The grey-level image contains more information than the binary-level one. The method does not search for simple black to white transitions along a scan line, but analyses directly the grey-level profile or its derivative. The destructive binarization step is avoided;
- b. Rotation is performed on the original grey-level image using a linear re-sampling algorithm that better preserves the information than the nearest neighbor method;
- c. Grey-level transition along any direction can be computed with sub-pixel accuracy.

### 3.1 Detection of the grey-level transitions

In this work, grey-level transitions have been analyzed at the sub-pixel scale using the tools implemented into the EasyGauge library (Euresys).

Depending on the nature of the image the scan line profile or its derivative is considered. Peaks along the profile are identified to determine the transitions positions. A peak is the area comprised between the profile (or its derivative) and a horizontal user-defined threshold level. All pixel values within the peak are taken into account to compute the exact transition location.

Four parameters help to detect valuable transitions:

- Threshold level* : delimits significant peaks in the data profile;
- Amplitude of the transition*: fixes the value of an offset added to the threshold level to improve noise immunity.
- Minimal area of the transition*: fixes the minimal area between the peak curve and the horizontal level;
- Thickness*: fixes the number of parallel segments used to extract the data profile.

The three last parameters allow for reducing the influence of noise on the transition detection. In practice, parasite transitions will perhaps fit the threshold level but their peak will neither be high enough nor large enough to be accepted as a relevant one.

The detection can eventually be improved by applying a Gaussian filter along the profile. Effectively, this will erase noise while helping to keep real transitions.

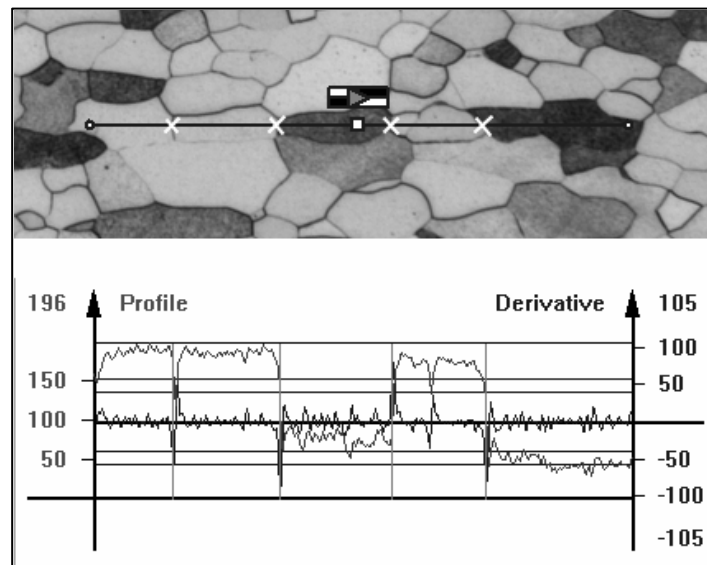


Fig. 1: A scan line drawn in a portion of image with its associated profile and derivative values. Found transitions for specified measurement parameters are represented by crosses.

Depending of the type of image to be analyzed (etched mono-phase, multiphase, polarized,...), two types of transitions can be relevant :

- “White to black to white” transitions correspond to light grains with darker boundaries. In this case, the transitions are detected along the profile. The inverse case (black to white to black transitions) is just treated the same way.
- “Black to white” or “white to black” transitions correspond to dark grains in a light matrix or vice-versa. They are detected along the derivative profile. This way to proceed strongly improves the procedure. Actually, the pixels are not treated individually anymore but the relative difference between adjacent pixels is considered, which fits the definition of a transition between two phases.

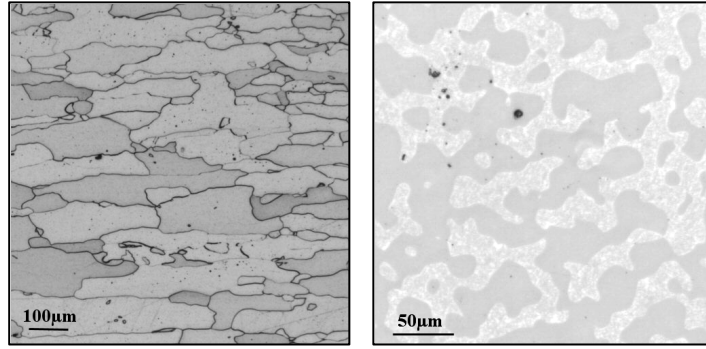


Fig. 2: The left image shows light grains separated by darker boundaries. The right image shows a mix of light and dark phases.

### 3.2 Implementation of the method

A validation program has been implemented following the three steps described below:

- Circumscription of a circular area of interest within the image. The choice of a circular mask prevents any anisotropy bias induced by the rectangular shape of the image frame;
- Detection of the transitions inside the mask for a specified direction. The transitions are detected along profiles or derivatives following the rules mentioned at point 3.1. The intercept lengths are directly measured from the transition positions;
- Repetition of (b) for a given number of directions. This is achieved by rotating the image and re-sampling the pixels by means of a linear transform.

### 3.3 Representation of the results

Roses of intercept lengths are commonly represented by plotting the mean intercept length along the different measurement directions.

The information is then usually modeled by fitting an ellipse which major and minor axes correspond to the maximal and minimal mean intercept lengths, and which inclination of the major axis (azimuth) indicates the preferential orientation of the grains. The ratio of the two axes is called the aspect ratio.

In order to retain all analytical information before proceeding to the modeling, it appears to be more efficient to display the whole histogram of intercept frequencies for any orientation class in the plane. This results in a grey-level rose of intercept lengths as shown in fig. 3.

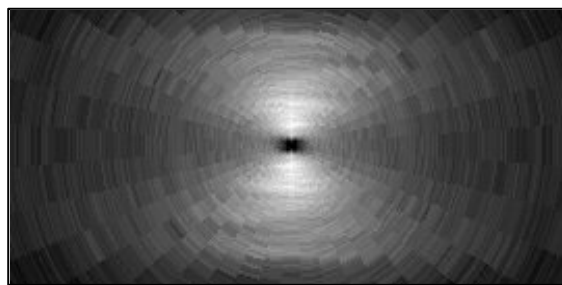


Fig. 3: Grey-level version of the rose of the intercept lengths. Intensity levels represent frequencies for the corresponding lengths.

Basic statistics such as percentiles, mean and median can easily be computed for each orientation and summarized into a synthetic rose of intercept lengths as shown in fig. 4.

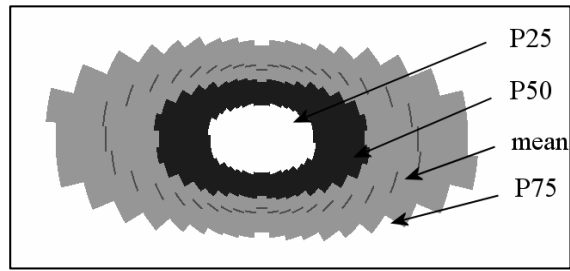


Fig. 4: Percentile rose of the intercept lengths

### 3.4 *G Grain size*

A common use of the mean intercept length is the computation of the *G* value, as described in the norm ASTM 1382. *G* value has been used by metallographers since 1950, and is still considered as the grain size reference value.

It can be computed from the following empirical equations :

$$G \approx (6,643856 \log \overline{N_L}) - 3,288 \text{ with } \overline{N_L} \text{ in } \text{mm}^{-1}$$

$$G \approx (-6,643856 \log \bar{l}) - 3,288 \text{ with } \bar{l} \text{ in } \text{mm}$$

Where  $\bar{l}$  is the mean lineal intercept distance and  $\overline{N_L}$  is the number of grains intercepted per unit length.

The ASTM 1382 also recommends to give the 95% confidence intervals based on a normal distribution.

## 4 EXAMPLE

Fig. 5 is a low carbon steel image of 1,45mm diameter. A centered region of interest (diameter of the image width) delimits the analyzed area.

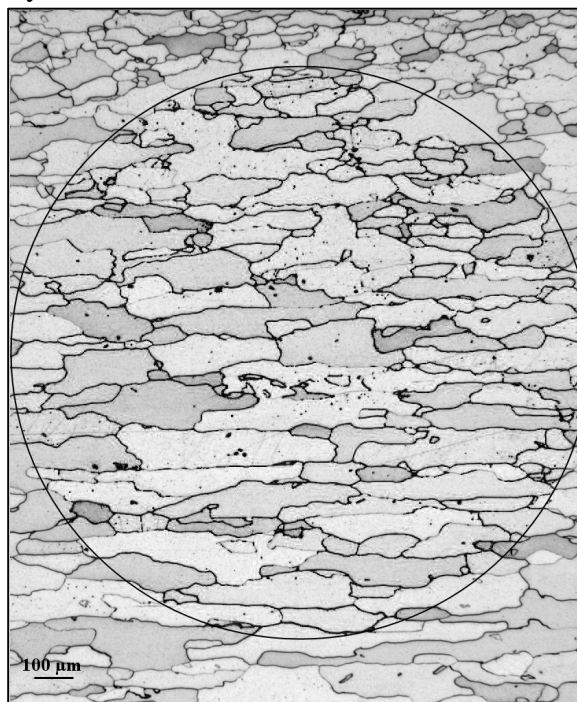


Fig. 5: Image of a low carbon steel.

Intercepts have been counted every nine degrees. No Gaussian filter was applied to the image, and no spacing was introduced between the grid lines, which means that each pixel line of the region was scanned.

The corresponding roses are the ones showed in fig.3 and fig. 4.

Table 1 shows the results obtained by the grey-level intercept method.

Image width (pixels)	840
Image height (pixels)	1016
ROI diameter (mm)	1,45
Mean intercepts count $C_0$	13606
Mean intercept lengths $l$ (mm)	0,07
Intercepts count/unit length $N_l$ (mm <sup>-1</sup> )	14,14
G grain size	4,5
Aspect ratio	2,2
Azimuth (°)	0

Tab. 1 Results of grey-level intercept analysis on the low-carbon steel image (fig.5).

## 5 CONCLUSIONS

This work resulted from two beliefs concerning grain size computations from sections:

- The intercept method is the most efficient and robust way to solve the problem of grain size computation. It is less sensitive to poor grain boundary extraction from grey level images.
- The original grey-level image must be processed directly. The first reason is that it contains more information than the binary one, which implies a more accurate detection of the intercepts. The second reason is that the grey-level image processing tools are less destructive then their binary equivalent.

Additional work is needed to treat images containing many phases, which implies to analyse the scan line profile and its derivative at the same time.

Finally, further work will focus on the establishment of optimal estimators to differentiate among a large range of grain interlocking textures.

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